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Developments of Optimal Strategies for Structural Health Monitoring

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1. Introduction

A stochastic inverse methodology for NDT arising in electromagnetic imaging has been investigated. Two NDE applications using MCMC approach have been solved at the course of this project. One is in the identification of electromagnetic material parameters and the emphasis is on one-dimensional scattering of a dielectric slab. The other problem is a quantitative evaluation method for aging properties of cable insulation. In the sequel, the achievements for the above two research results are summarized. The refereed publications out of this AFORD works and the collaboration works related in this project are summarized in the final part of this report.

2. Inverse Problem for Electromagnetic Propagation in a Dielectric Medium

An inverse methodology arising in electromagnetic imaging was discussed within the stochastic framework. Taking into account that guided microwaves propagate with phase velocities depending upon the frequency of the waves, a computational method for identifying dielectric properties of target materials was proposed. The data driven model based on one-dimensional scattering of dielectric slab was considered for the nondestructive test of micro-waveguide. The numerical scheme of data driven model was constructed using the finite-difference time-domain (FDTD) method. The posteriori distribution of material quantities can be evaluated by likelihood functional and by probability of detection. The likelihood functional is described by the data driven model, while the probability of detection is considered as a priori distribution of material quantities. Thus the estimated material quantities were evaluated using Markov Chain Monte Carlo (MCMC) simulations. The feasibility and validity of the proposed method

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14. ABSTRACT
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15. SUBJECT TERMS
nondestructive evaluation, electromagnetic NDE, Aerospace Materials, Structural Health Monitoring

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were demonstrated through the numerical experiments.

3. Nondestructive Interrogation Method for Degradation of Electrical Cables

Insulation degradation of electrical cables of instruments and control facilities is one of the critical phenomena for ageing management. In this research, the same method was applied to the quantitative nondestructive evaluation of cable degradations. Time–resolved Microwave Dielectric Absorption (TRMDA) enables to measure evanescent electrical field leaking from the probe into the cable insulation using cavity resonator. Although there exist some commercial products for implementation of TRMDA method, the current NDT is limited to continuous surveillance under indirect measurements. The approach considered here is superior to the conventional technology because the focus of the method is to identify directly material quantities of electrical cables. With the background knowledge of Debye formulation, the proposed method allows us identifying two relative permittivities of the electrical cable in the limit of the static field and very high frequency. Those two parameters are quite sensitive with respect to insulation degradation of cables. The feasibility and validity of the proposed method were also shown through the numerical experiments.

4. Summary of Achievement

Throughout this research project, two major advantages for the new philosophy of NDT inversion were found. The use of classical nonlinear least square algorithm only brings the average and the standard deviation of material quantities under NDT inversion. This fact is known as the ill-posed problems. In the other words, the most inverse problems appeared in engineering fields have many candidate solutions. Instead, the proposed approach provides the informative distribution of the unknown quantities. This implies that the inversion treated here shows no distinct solution but the posteriori probability density. This is much affordable for the reliability centered maintenance (RCM). The other aspect is concerned with the feasibility of condition monitoring. The essential role of NDT is to predict the lifetime estimate at the current stage of the structured health. Generally speaking, POD can be usually defined according to the design structure of the system. Nevertheless, even in the same structured system, the aging behaviors depend on the operational conditions as well as environmental circumstances. From this fact,

the likelihood functional affects each history of the structured system. As a result, the application of Bayes formula to the NDT inversion make it possible to improve and to modify the prescribed POD. For that means, the proposed approach is very effective for the probabilistic life management.

5. Refereed Publications

[1] Fumio Kojima, “Inverse Problem for Electromagnetic Propagation in a Dielectric Medium using Markov Chain Monte Carlo Method”, Proceedings of the 42th ISCIE International Symposium on Stochastic System Theory (SSS’10) Okayama, November 26-27, 2010 pp. 208-212.
[2] Fumio Kojima and Teruo Usami, “Nondestructive Interrogation of Dielectric Materials using Markov Chain Monte Carlo Method for Structural Equation Model”, Studies in Applied Electromagnetics and Mechanics, Electromagnetic Nondestructive Evaluations, IOS Press, Amsterdam, (in Press).
[3] Fumio Kojima and Jeremy S. Knopp, “Inverse Problem for Electromagnetic Propagation in a Dielectric Medium using Markov Chain Monte Carlo Method”, International Journal of Innovative Computing, Information and Control (IJICIC) (accepted for publication)

6. Collaborations related in AOARD work

[1] Professor H. T. Banks, Director, Center for Research in Scientific Computation, North Carolina State University, Raleigh NC USA

Research collaboration has been performed during November 14 – 17, 2010 and April 17-21, 2011. Project on material damage parameter estimation for electromagnetic acoustic interaction has been started. We will accomplish the convergence properties of inverse solution of nondestructive test using electromagnetic acoustic transducer.

[2] Mr. Jeremy S. Knopp, Researcher, AFRL/RXLP, Nondestructive Evaluation Branch, Materials and Manufacturing Directorate, Air Force Research Laboratory, Dayton OH USA

Research collaboration has been performed during November 18 – 21, 2010 and April

22-25, 2011 in Dayton. Also he visited Kobe University during January 26- 28, 2011.
We discussed new inverse methodologies for structural health monitoring which includes how statistical approach by merging modeling of material failure process and how to design inverse methodologies.